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AUTHOR Moore, R. L.; And Others
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ABSTRACT

This manual is designed to assist uses of fumigant pesticides prepared for certification under the Michigan Pesticide Control Act of 1976. An introduction with the explanation of fumigation is presented. The nine sections included describe: (1) Nature and effects of fumigants; (2) Modern fumigants; (3) Precautions to follow when using fumigants; (4) Use of safety devices; (5) Types of fumigation enclosures; (6) Greenhouse fumigation; (7) Fumigation of grain in bulk; (8) Soil fumigation; and (9) Fumigation procedures. A list of self-help questions and instructions for completing the questions are presented at the end of each section. (HM)

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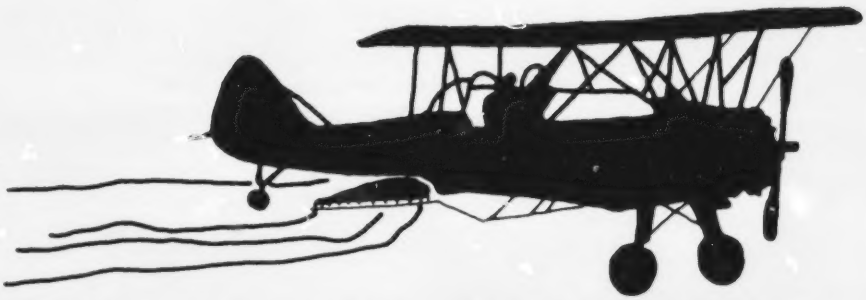

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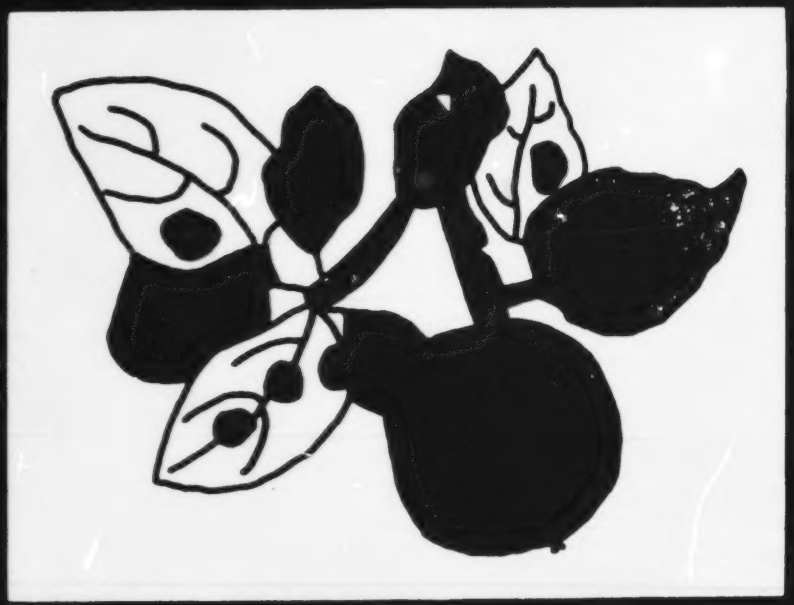
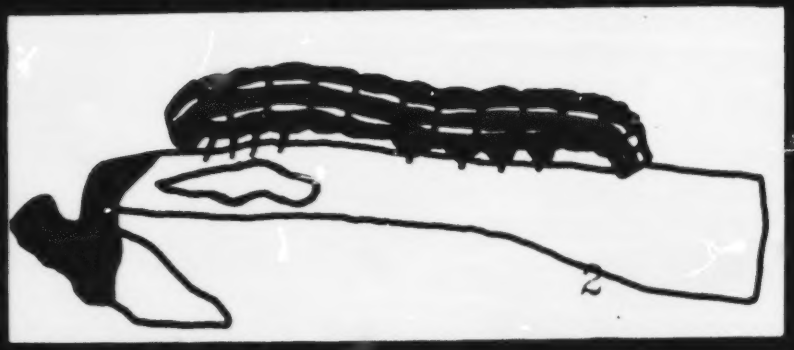
SAFE, EFFECTIVE USE OF PESTICIDES
A MANUAL FOR COMMERCIAL APPLICATORS





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Space Fumigation

Extension Bulletin E-1032-12

Preface

This bulletin is intended to assist uses of fumigant pesticides, prepared for certification under the Michigan Pesticide Control Act of 1976. The manual was prepared by: Mr. R. L. Moore, Animal and Plant Health Inspection Service, United States Department of Agriculture; Mr. R. L. Mesecher, Plant Industry Division, Michigan Department of Agriculture; and Dr. G. Bird, Department of Entomology, Michigan State University.

A list of self-help questions and instructions for completing the questions are at the end of each section. If you encounter difficulties in using the manual, please consult your county agricultural extension agent or representative of the Michigan Department of Agriculture for assistance.

Some suggestions on studying the manual are:

1. Find a place and time for study where you will not be disturbed.
2. Reread the entire manual through once to understand the scope and form of presentation of the material.
3. Then study one section of the manual at a time. You may want to underline important points in the manual or take written notes as you study the section.
4. Answer, in writing, the self-help questions at the end of each section. Instructions on how to use the self-help questions in your study are included with the questions. These questions are intended to aid in your study and to help you evaluate your knowledge of the subject. As such, they are an important part of your study.
5. Reread the entire manual once again when you have finished studying all of its sections. Review with care any sections that you feel you do not fully understand.

This manual is intended to help you use pesticides effectively and safely when they are needed. We hope that you will review it occasionally to keep the material fresh in your mind.

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INTRODUCTION

Fumigation is the distributing of a chemical pesticide as a gas through spaces and materials. Because gas molecules exist separately and independently, they spread widely into small cracks and crevices and penetrate into tightly packed materials. The term "space fumigation" designates generally a wide range of treatments in enclosed spaces which either contain infested materials or themselves have residual insect populations. This spreading of individual molecules differentiates fumigants from aerosols such as smokes, fogs or mists. The aerosols are discharged as very fine particles which remain suspended in the air long enough to be distributed. Aerosols are unable to penetrate even small distances into materials. For aerosols to be effective, the pest must be exposed or easily reached.

All fumigations should be under the supervision of an individual who knows the nature of the chemical being used and its hazards. All effective fumigants are potentially dangerous to plant, animal, and human life and should be handled with due care and judgment.

Fumigants offer the following advantages over other pesticides:

1. Most fumigants commonly used are toxic to all animal pests, insects, spiders, mites and rodents.
2. The use of fumigants is usually the quickest method of controlling pests.
3. Fumigants will usually reach pests where sprays, powders or dusts cannot be applied.
4. Some fumigants can be used to kill pests in or near food, leaving no harmful residues, whereas other pesticides may contaminate or taint food.
5. In specific situations, fumigants may be less expensive than repeated treatments by sprays or dusts.

Some disadvantages of fumigants are:

1. Most fumigants are very toxic to man
2. Fumigants leave no residual pest control after aeration.

3. More specialized protective equipment, such as gas masks, gas leak detectors, etc. are required.
4. The application of fumigants requires more technical skill.
5. The labor involved may make the cost high.
6. More application and operational equipment may be needed.
7. The use of fumigants may cause inconvenience to people who live or work in the building.
8. More than one technician must always be present in any fumigation operation.
9. Some fumigants are expensive, corrosive, or may leave residues.
10. Special permits or licenses are required in many areas.

NATURE AND EFFECTS OF FUMIGANTS

How Fumigants Kill Pests

It has been very difficult to determine exactly how fumigants affect insects. Scientists have explored the question for many years but are not in complete agreement as to just how different fumigants cause death. In general, fumigants reach the tissues of insects through the respiratory system. The highest percentage of kill is caused by the entrance of the fumigant into the cells. In most insects, oxygen is taken into the body through the spiracles. Once inside the body, oxygen and the accompanying fumigant are diffused through the thin cell walls. Inspiratory movement of the insect's abdomen and thorax acts to assist diffusion. The matter of diffusion has a practical bearing upon commodity fumigation. Insects are most active during periods of optimum temperatures as they breathe normally and, therefore, absorb more fumigant than they do during cold, inactive periods. This plus the fact that at the lower temperatures gas is less active is one of the reasons that higher dosages of fumigants must be used as temperature decreases to compensate for inaction of the insect. A certain amount of gas will enter the cells of inactive insects, but high concentrations are required to diffuse into the cells and kill the pests.

Some fumigants appear to kill insects by preventing the assimilation of oxygen in the cells. Others may kill by mechanically preventing oxygen from reaching the insect. Methyl bromide and ethylene dibromide appear to kill by affecting the enzymes in some way which prevents tissues from uniting with oxygen.

When fumigating, lethal fumes are released within an enclosure. The person applying the fumigation treatment cannot see and, in some cases, cannot smell the fumes. The pests which he seeks to kill may be hidden away in the heart of a grapefruit or a bale of hay, but the invisible fumes must be capable of killing them regardless of the stage of development or where they are located. Therefore, fumigation operators need to know the potential of fumigants and how to apply them properly.

The most important environmental factor influencing the action of fumigants on insects is temperature. In the range of normal fumigating temperatures from 10°C. to 35°C. (50°F to 95°F), the concentration of the fumigant required to kill a given stage of an insect species decreases with the rise in temperature. From the purely biological standpoint this is mainly due to the increased rate of metabolism of the insect's response to the rise in temperature. Also, physical absorption of the fumigant by the material containing the insects is reduced and proportionately more fumigant is available to attack the insects.

Nature of Fumigants—General

Fumigants are used in various forms and dosages according to the nature of the commodities and pests involved. Certain generalizations may be made pertaining to killing insect pests in commodities. The state of development and activity of the target pest is important. Active adults normally are easier to kill than inactive or hibernating adults. Immature stages of insects generally require higher dosages or longer exposure for complete mortality than do active adults. The amount of free air space compared to the size of the load, the porosity of the load, the kind of material, and the location of the pest in the load all affect the dosage and exposure period. Finely ground materials, such as alfalfa and cottonseed meal, have a large surface area and are more sorptive than whole grain or inert items such as scrap iron.

At lower temperatures higher dosages are required to insure that lethal amounts reach the center of the load or the interior portions of fruits and vegetables.

Tests in recent years indicate that residues resulting from methyl bromide fumigation are lower when temperatures are low. This is true even though the concentration and exposure are greater at these temperatures.

The Predeath Behavior of Fumigated Insects

Insects that have been fumigated with methyl bromide or ethylene dibromide die slowly. Death occurs much more quickly at higher temperatures than at low temperatures. Temperature determines the molecular rate of activity of chemical. At higher temperatures, the fumigant disperses more rapidly, thereby getting to the pest more quickly.

Treated insects may soon become unable to walk or fly in a normal manner. They usually come to rest on their backs and eventually are unable to recover from that position; however, they may move their head, legs, or antennae for several days before death finally occurs. It should be noted that some fumigants, such as carbon disulphide and cyanide, at sublethal concentrations may anesthetize insects so that they appear to be dead shortly after fumigation only to revive and continue a normal life. It has been observed that decomposition sometimes occurs in the abdominal segments before the insect actually dies. Insect activity, when observed shortly after exposure to slow-killing fumigants, such as methyl bromide and ethylene dibromide, may be disappointing to inexperienced persons. The effect on insects that have been exposed to lethal dosages of these gases is accumulative and regardless of how long it takes to kill them they never recover.

MODERN FUMIGANTS

There are many chemical compounds which are volatile at ordinary temperatures and sufficiently toxic to fall within the definition of fumigants. In actual practice, however, most gases have been eliminated on account of unfavorable properties, the most important being chemical instability and destructive effects on materials. Damage to materials may take place in several ways, as follows:

1. Excessively corrosive compounds attack shipping containers or spoil the structure and fittings of fumigation chambers or of other spaces undergoing treatment.

2. Reactive chemicals form irreversible compounds which remain as undesirable residues in products. In foodstuffs such reactions may lead to taint or the formation of poisonous residues. Other materials may be rendered unfit by visible staining or by the production of unpleasant odors.

3. Physiologically active compounds may destroy or greatly injure growing plants, fruit or vegetables, and may adversely affect the germination of seeds.

Highly flammable compounds are not necessarily excluded if dangers of fire and explosion can be controlled by the addition of other suitable compounds, or if fumigation procedures are carefully designed to eliminate these hazards. Toxicity to human beings is not usually a cause for exclusion. All known fumigants are toxic to man to a greater or lesser degree, and ways can be devised for their safe handling under the required conditions of application.

Table 1, which lists the limited number of insecticidal fumigants in use today, demonstrates the severity of the pruning process applied to gaseous chemicals before they are adopted for practical use as fumigants. It will be noted from this table that many of the fumigants listed do, in fact, exhibit one or more of the undesirable properties discussed above. This fact shows that the "ideal" fumigant has not as yet been found, and it is quite probably that it never will be. Nevertheless, these fumigants are highly useful in their own particular spheres of application.

Liquid Drain Fumigants

Liquid grain fumigants are chemical formulations used to protect stored grain from such insect pests as Angoumois grain moth, rice weevil, granary weevil, common cadelle, Indian meal moth, etc.

The fumigants are applied to the grain as liquids. They evaporate and the heavier-than-air vapors sink into and spread through the grain.

The choice of fumigant mixture and dosage should be based on various factors involved in each storage condition. The type of insect, kind of grain, temperature, moisture content, etc. must be considered. Specific guidelines for grain fumigation can be obtained from The Dow Chemical Company, Midland, Michigan 48640.

There are two basic methods of applying liquid grain fumigants:

1. Surface application with natural or gravity distribution.
2. Forced distribution with air recirculation equipment.

Surface application is the easiest and most convenient method, especially where small quantities of grain are stored. The fumigant is sprayed uniformly in coarse droplets over the top surface of the grain mass. As the fumigant vaporizes, the vapors are carried throughout the grain mass by convection currents. Distribution is obtained both by these fumigant laden air currents and the sorption of the fumigant on the grain kernels.

Forced distribution of liquid grain fumigants by air recirculation equipment is a relatively new development. The fumigant is applied above the grain surface in the finest droplets possible while fans are moving air through the grain. Vaporization of the fumigant is obtained, using the heat available from the grain. Because of the mechanical means for moving the fumigant-air mixture through the grain, the fumigant should consist of ingredients having the lowest sorption rates. The advantages of this method are rapid distribution of the fumigant, low sorption rates of fumigant, more efficient use of fumigant, and rapid removal of fumigant after exposure period is complete.

As with all fumigants, safety precautions should be carefully followed when applying liquid grain fumigants. In particular:

- Read product label before using.
- Have someone close by at all times in case of an accident.
- Pump fumigants from containers to sprayer in well ventilated areas, preferably outdoors.
- Use appropriate gas mask at all times.
- Avoid skin contact and inhaling vapors.

- If fumigant is spilled on shoes or clothing, remove them immediately, and do not wear them again until all fumigant odors are gone.

TABLF 1. Characteristics of Some Fumigants

Name and Formula	Molecular Weight	Boiling Point (C° at 760 mm pressure)	Solubility in Water (g./100ml)	Flammability (% by volume in air)	Commodities Treated and Remarks
Acrylonitrile	53.06	77.0	7.5 at 25°C	3.17	Tobacco and plant products; also for spot treatment. Injures growin plants, fresh fruits and vegetables Marketed with carbon tetrachloride.
Carbon disulphide CS	76.13	46.3	0.22 at 22°C	1.25-44	Grain. Usually as ingredient of nonflammable mixtures.
Carbon tetrachloride CCL	153.84	77.0	0.08 at 20°C	Nonflammable	Only weakly insecticidal. Used chiefly in mixture with flammable compounds in grain fumigation to reduce fire hazard and aid distribution.
Chloropicrin CCL, NO	164.39	112.0	Insoluble at 20°C	Nonflammable	Grains and plant products. Safe with seeds; injurious to living plants, fruits, and vegetables. Highly irritating lachrymator. Bactericidal and fungicidal.
Ethylene dibromide CH,Br,CH, B4	187.88	13110	0.43 at 30°C	Nonflammable	General fumigant. Particularly useful for certain fruits; may inju growing plants.
Ethylene dichloride CH,Ci, CH, Cl	98.97	83.0	0.87 at 20°C	6-16	Seeds and grains. Usually mixed with carbon tetrachloride.
Ethylene oxide CH, O CH	44.05	10.7	Very soluble at 20°C	3-80	Grains, cereals, and certain plant products. Toxic at practical concentrations to many bacteria, fungi and viruses. Strongly phytotoxic; affects seed germination.

TABLE 1. - Continued

Name and Formula	Molecular Weight	Boiling Point (C° at 760 mm pressure)	Solubility in Water (g./100ml)	Flammability (% by volume in air)	Commodities Treated and Remarks
Ethyl formate H.COO.C, H	74.05	54.0	11.8 at 25°C	2.7-13.5	Application to individual packages of dried fruit.
Hydrocyanic acid gas HCN	27.03	26.0	Very soluble at 20°C	6-41	General fumigant, but may be phytotoxic. Safe on seeds but not recommended for fresh fruits and vegetables.
Methyl bromide CH, Br	94.95	3.6	1.3 at 25°C	Nonflammable	General fumigant. May be used with caution for nursery stock, growing plants, some fruit, and seeds of low moisture content.
Methyl formate COO CH	60.03	31.0	30.4	5.9-20	Usually mixed with CO. Formerly used for grain, now mainly for stored furs.
Paradichlorobenzene	147.01	173.0	0.008 at 25°C	(Flash point) 66°C	Control borers in peach trees and soil insects. Applied as crystals. May affect seed germination.
Propylene oxide CH, CH, O CH	58.08	34.0	40	2.1-21.5	For individual packages of dried fruit. Toxic to bacteria and strongly phytotoxic.
Trichloroethylene CHCL:CCl	131.4	220.0	Insoluble	Nonflammabel	Nonflammable ingredient of grain Sometimes used alone.

SELF-HELP QUESTIONS

Now that you have studied this section, answer these questions. Write the answers with a pencil without referring back to the text. When you are satisified with your answers, see if you are correct by checking them in the text. Erase your answer and write in the correct answer if your first answer is wrong.

1. How does a fumigant differ from an aerosol?

2. What is the normal range of temperatures for fumigation?

3. Should dosages of fumigants be increased or decreased at low temperatures?

4. Do insects die quickly after exposure to methyl bromide?

5. What are some ways that fumigants can damage materials?

6. Why is carbon tetrachloride commonly mixed with flammable fumigants?

7. What are the two basic methods of applying liquid grain fumigants?

PRECAUTIONS TO FOLLOW WHEN USING FUMIGANTS

Preliminary Planning

A. Become fully acquainted with site and commodity to be fumigated, including:

1. General layout of structure, connecting structures, adjacent structures, and escape route, above and below ground.

   a. Check over equipment to insure that product flow has ceased and that equipment has been made as tight as practicable to prevent drafts and/or leakage from it.

   b. Check all spouts, conveyors, conduits, heat pipes or other possible openings leading from area to be fumigated.

2. Determine the number and identification of persons who routinely enter the area to be fumigated, and the proximity of other persons and animals.

3. The specific commodity and its mode of storage and condition.

4. The previous treatment history of the commodity, if available.

5. Accessibility of utility service connections.

6. Nearest telephone or other communication facility.

7. Emergency shut-off stations for electricity, water, gas, etc.

8. Ascertain and post current emergency telephone numbers, i.e., fire, police, hospital, physician.

B. Select a fumigant or combination of fumigants, registered by EPA for the work involved.

1. Make sure the chemical or chemicals selected will not result in residues that may be illegal under Sections 408 and 409 of the Federal Food, Drug and Cosmetic Act.

2. Check, mark and prepare the points of application.

C. Study directions, warnings, antidotes, etc., on the label and on the manufacturer's instruction manual.

D. Notify local fire and police authorities and other security personnel as to location, the chemicals to be used, proposed date and the time of use, type of gas mask and canister required, and fire hazard rating.

E. Make certain that local medical organizations are informed of your fumigation practices and the specific materials in use.

F. Provide authorities with pertinent safety literature on the materials to be employed.

G. Arrange for standby equipment, replacement parts and alternate plan of action.

H. Inform all employees of the operational schedule, potential hazards to life and property, and the required safety measures and emergency procedures.

I. Prepare warnings signs for posting treated areas, provide for security of buildings, and arrange for watchmen when required.

J. Have available first aid equipment and antidotes where applicable.

K. Plan for application from outside the structure whenever possible.

L. Plan for ventilating the treated space and commodities when the required exposure is terminated. Do this before treatment is started.

M. Areas used for storage of fumigant chemicals should be properly identified and provide the conditions required by the manufacturers' directions.

N. Make sure that there are no open fires, motors, etc., that could spark, or hot surfaces, such as heat pipes and electric fixtures, within the space to be fumigated.

O. Provide fans for distribution of the fumigant where applicable.

P. Provide gas sampling and/or detection devices.

Q. Make a final check to clear all personnel and animals from the space to be exposed to the fumigant.

Personnel

A. Assign at least two persons to each fumigation.

B. In circumstances where entry into a fumigated area is essential, use a buddy system of two persons (not three).

C. Employees actively taking part in a fumigation should be in good physical condition, and:

1. Should have physical examinations at least annually and more often as conditions require, and employee health records should be maintained current.

2. Should abstain from alcoholic beverages for 24 hours prior to and 24 hours after a fumigation job.

3. Employees having colds or other conditions which impair breathing should not participate.

4. Employees undergoing medical or dental treatment should not participate unless specifically authorized to do so by a physician.

D. All operating personnel should be instructed in first aid and other emergency procedures, including personal decontamination.

E. The use of specific antidotes or first aid should be understood by operating personnel.

F. All accidents should be reported immediately to employer or supervisor. Personnel handling fumigants should be cautioned to report all indications of illness or physical discomfort regardless of their apparent minor nature. These may include but not be restricted to any or all of the following: dizziness, diarrhea, nausea, headaches, and lack of coordination.

G. Instruct all operating personnel in the hazards that may be encountered in the misuse of the chemicals selected and in the selection, operation, and maintenance of all protective devices or procedures requires.

Protective Equipment

The equipment recommended in this section is to be employed to prevent loss or injury to life. The recommendations of the fumigant manufacturer concerning specific protective equipment and clothing should be rigorously observed. The limitations on operation conditions and performance of protective devices should be understood and observed.

A. When possible, arrange for two-way radio communication among employees applying fumigants or, in emergencies, entering treated areas.

B. All protective equipment should be stored so as to insure maximum life of the device and be readily accessible to employees at all times.

C. Self-contained oxygen supply breathing apparatus is preferable in certain situations. It does not prevent sorption through the skin.

D. Canister-type gas masks should be provided with a supersize canister and with a canister mounted as appropriate to the gas mask.

E. Canister-type gas masks:

1. Are ineffective when breathable oxygen is too low.
2. Do not prevent sorption through the skin.
3. Will not remove toxic gases if the concentration is above the level stated on the canister.
4. Require different types of canisters for different toxic gases.
5. Operating conditions listed for a canister apply to fresh canisters only.
6. Used canisters should be mutilated to prevent reuse.
7. Canisters should be used one time only.

F. Personnel using canister-type gas masks:

1. Must receive instruction in the proper care and use of gas masks.
2. Should understand the limitations of a gas mask.
3. Must always check:

a. Proper type of canister—read the label.

b. For airtight face pieces.

c. For airtight hoses and connections.

d. Individual need for special glasses.

e. That the canister is unused.

4. Practice using an actual gas mask and become acquainted with the feel of such a device.

G. Self-Contained Breathing Apparatus (SCBA):

The wearer carries his own breathing air with the SCBA. Its use is required in atmospheres immediately dangerous to life or health, for the rescue of personnel, or escape. The SCBA should be properly fitted and used according to instructions. These instructions are affixed to the container for the SCBA. It is recommended that each potential user practice with the unit before actual use. When properly used, the positive pressure demand system will prevent harmful gases from entering and provide breathing air in low oxygen areas.

H. Air Supplied Respirator

There is one basic difference between the SCBA and the Air Supplied Respirator. The SCBA is self-contained, whereas the Air Supplied Respirator depends on a remote source of air. It is connected to this remote source by a hose. The Air Supplied Respirator has the advantage of a continuous supply of air, however, freedom of movement is somewhat restricted due to the connecting hose. Care should be taken to avoid cutting or damaging the hose.

I. Personnel required to enter fumigated tanks and similar enclosures should wear a rescue belt. They should be under constant observation from outside.

Application

A. All applications should be made in accordance with the fumigant manufacturer's recommendations.

B. Areas to be treated should be posted immediately prior to application.

C. Apply fumigant from outside where possible.

D. Personnel applying fumigants should not enter into areas where fumigant gas or vapor is being discharged except in extreme emergencies.

E. Take into consideration prevailing wind and other weather factors.

F. Post warning signs.

G. Provide watchmen where required or necessary.

Postapplication Operations

A. Provide watchmen where required or necessary.

B. Ventilate and aerate in accordance with structural limitations.

C. Turn on all ventilating or aerating fans where appropriate.

D. Before re-entry, use a suitable gas detector to determine fumigant concentration, so that appropriate precaution may be taken. Never rely on fumigant warning odor during re-entry or aeration. Wear a gas mask until the area is determined free of gas.

E. Check for gas concentrations in areas which aerate slowly.

F. Remove warning signs when aeration is complete.

G. Dispose of empty containers.

H. Return unused chemicals in properly and clearly labeled containers to storage area.

USE OF SAFETY DEVICES

How to Use a Halide Gas Detector

While the halide gas detector has been used for many years, its importance is enhanced by the development of treatments employing enclosures other than the conventional fumigation chamber. It is an operational as well as a safety device, since the elimination of fumigant leaks increases the efficacy of operation and reduces harmful concentrations outside the area under treatment. As a precautionary measure, it should be used regularly in rooms in which chambers are located, particularly when the building also houses offices or other occupied work areas.

Principles of operation: The halide gas detector is used to indicate the presence and approximate concentration of methyl bromide in the air. This is accomplished by passing the air to be tested over a red hot copper plate or cone through or over which flame is passing. The intensity of colors imparted to the flame indicates the presence and concentration of methyl bromide in the air. The leak detector also reacts similarly with many other halide gases, including freon, carbon tetrachloride, and ethylene dibromide. The following are the approximate methyl bromide concentrations associated with the color intensity of the flame:

PPM	Lbs/1000 cu. ft.	Flame Color
0	0	No color
25	0.00625	Faint fringe of green
50	0.0125	Moderate green
125	0.031	Green
250	0.0625	Strong green
500	0.125	Strong green-blue fringe
800	0.20	Strong blue-green
1000	0.25	Blue

This table of flame colors for various ppm's of methyl bromide applies only when the detector is operated at its most sensitive rate; that is, when the flame is reduced to the lowest rate sufficient to keep the reactor plate or cone red hot. Also, in using the detector at night, the flame has a bluish cast which has to be taken into consideration.

Description: Basically, all halide detectors are quite similarly constructed, differing only in detail by the various manufacturers. Each consists of a fuel tank, a valve assembly to regulate fuel flow, a burner head assembly where the fuel and air mix and unit, and the reaction place or cone assembly where the visible flame reacts in color to the halogen fumigants. The air mixture to be tested is fed to the burner head assembly by an attached search hose.

The halide detector is relatively trouble free. The burner head orifice is extremely small and must be kept free of clogging with dust or other debris. The reaction plate or cone will need replacing occasionally.

Usage: The halide leak detector is made operable by holding a lighted match in the window opening of the burner tube and turning the valve slowly to the left. After the reaction plate or copper plate has heated to a red hot color, the flame should be adjusted to the minimum size to maintain that color. The detector is now ready for use and this is accomplished by holding the open end of the search hose on, in, or near the area or article to be tested. As the air sample thus drawn into the burner passes over the heated reaction plate or cone, the flame color changes if methyl bromide or any other halogen is present.

Since the operating halide leak detector contains an open flame, there must be a strict adherence to the obvious safety practices. Even when not in operation, it is advisable not to store the detector in a frequently inhabited room, the fuel being a flammable gas under pressure. Do not use the halide detector in mills, elevators, or other enclosures where there is a possibility of dust explosion.

How to Use a T/C Analyzer

The thermo conductivity analyzers (TAC) are scientific instruments specifically designed for determining the concentration of fumigant gases within the chamber or other enclosure while the actual fumigation is being conducted.

Description: The TCA (Fumiscope, Fumiscope Jr., and Gow-Mac) is light in

weight, readily portable by hand, completely contained in one compact cabinet, and requires no auxiliary equipment. It contains a thermal conductivity cell, a meter, a gas pump, controls, and may contain a gas flow meter. It operates on regular 115 volt alternating current or battery power. A gas drying tube is also included. This should be used with any TCA.

Principles of Operation: The difference in the thermal conductivity of the fumigant-laden air as compared with pure air is converted into electrical energy and is indicated on the meter as concentration in ounces of fumigant per 100 cubic feet. TCA's used in PPD have been calibrated for methyl bromide by the manufacturer prior to delivery.

When long sample lines are used a small vacuum pump may be used to draw the air-gas sample from the test point to the end of the line. This speeds up the readings on the gas analyzer. The following table illustrates this fact:

Line	Time Required for T/C Reading with Pump	Without Pump
1	55 sec	125 sec.
2	70 "	110 "
3	75 "	120 "
4	72 "	100 "

These lines were 150' - 200' long.

The proper procedure is to connect the line to be sampled to the vacuum pump while the reading is taken on another line. When the first reading is completed, remove the line from the vacuum pump and connect it to the T/C analyzer. Repeat this procedure until all readings are completed.

It is not recommended that the TCA be used for checking concentrations when fumigations are under vacuum since special procedures not herein prescribed would be required.

Although the TCA is designed to measure MB concentrations in the range of 0-100 oz. per 1000 cu. ft. (with close approximations up to 110 oz.) and is within 5 percent of accuracy in this range, it may be modified to measure 0-200 oz. for a modest fee, by being sent directly to the manufacturer. Since the TCA's

galvanometer responds linearly to gas concentrations, the MC-calibrated instrument may be used for measuring certain other gases by the use of specific multiplication factors which have been determined by laboratory studies. For example, carbon tetrachloride concentrations may be determined by multiplying the meter reading by 1.0, ethylene dichloride by 1.05, carbon disulfide by .85, and ethylene dibromide by 1.6.

Operational procedures: The proper use ot the TCA is discussed here under three general headings: (1) selecting the operational site, (2) standardizing the instrument, and (3) using the instrument for measuring fumigant concentrations. Because of the variety of fumigation situations, some adjustments may be necessary to meet specific needs. Nevertheless, this general outline should be helpful in establishing correct operational procedures:

1. Selecting the operational site for the TCA. The fumiscope should be close enough to the fumigation site to avoid the use of unreasonable lengths of sampling tubes, to allow for a constant surveillance of fumigation setup during testing, and to avoid interference with other activities in the area. It should be at a sufficient distance from the fumigation site to allow operator to function without undue safety hazard and to allow for easy exit in an emergency. Also to be considered is the avoidance of excessive wiring which could cause mechanical failure and increase the hazards of operator injury. If multiple locations are necessary during operation, to reach sampling tubes, care should be taken that each location is the best available.

   The TCA should be supported on a sturdy level surface, outside the traffic pattern, and protected from winds and excessive cold, avoiding the sun in hot weather. Some temporary shelter may need to be provided, such as a tarpaulin or nearby vehicle. Optimum operating temperature is 75°F.

   The gas analyzers used by PPD operate on 115-volt alternating current or battery power; for direct current a converter will be necessary. It is recommended that all 115 V. A. C. TCA instruments should be equipped with 3-wire grounding-type cords to minimize shock hazards.

(Modification instructions are available for present instruments.) Where 3-wire grounding-type electrical outlets are not available, a grounding adapter must be used in the electrical outlet and the green wire of the adapter attached to a good ground (water pipe, electrical conduit, etc.). To install the adapter, the "hot" side of the two-wire electrical outlet should be determined by use of a neon test lamp. Next, view the adapter from the 3-hole side with the hole for the grounding prong at the bottom, and insert the right-hand prong of the adapter into the "hot side of the 2-hole receptacle. Then attach the battery clip, or end lug, to a good ground.

These arrangements apply a ground to the case of the instrument and place the instrument fuse in the "hot side of the line. If the fuse "blows," suspect an insulation breakdown, short-circuiting the line voltage to the case.

Extension wiring should be kept to a practical minimum and should preserve the grounding arrangements just described. Either use 3-wire extension cords or attach the grounding adapter to the instrument cord. When feasible, raise extension cords to clear obstacles rather than leaving them at floor level.

2. Standardizing the gas analysis. This operation is the equivalent of adjusting the bathroom scales before weighing oneself. TCA is set up and the pump and meter switches set to the on position after connecting the instrument to the electrical outlet, checking the fuse if inoperable. Replacement fuses (Little Fuse or Buss #3AG1/2Amp.) should be kept available. Next the sampling tube is attached, using an adapter if of a size different from the inlet stem. Allow for a 5-minute warm-up (15 minutes if drying tube attached) before drawing an air sample. During this warm-up period the gas flow rate should be adjusted to 1 cu. ft. per hour (the Fumiscope Jr. has a rubber squeeze bulb in place of a pump), turning the knob counterclockwise to increase rate flow. When properly adjusted, the flow indicator should float at the mark 1 line in the calibrated glass cylinder, although it fluctuates slightly from a stationary position. The current adjustment should be made on those instruments with this

control. After warm-up, the meter needle is adjusted to a stable zero by dialing clockwise. Standardization is now completed pending the taking of concentration reading during the fumigation operations.

3. Probing for and measuring fumigant concentrations with standardized fumiscope. Commodity fumigations must be probed with a minimum of three sampling tubes, one in the center of a center bag or other items of commodity; one in an outside bag, bale of hay, or similar item; and one on the floor. Large lots should have additional sampling tubes in proportion of approximately one tube per 20 tons of commodity, mostly placed deep within the commodity. Each sampling tube should be labeled as to the location of the probe.

Machinery or equipment fumigations should also be probed with a minimum of 3 sampling tubes, one high in the headspace, on near the center of the machinery or equipment, and one on the floor. Before starting the fumigation the TCA should be given a tightness test while in operation. This can be accomplished by placing a finger over the far ends of sampling tubes. The flow ball on the flow meter should then fall to zero if the tubing and connections are tight.

In making gas concentration checks during the course of fumigation, the TCA should first be warmed up for approximately five minutes, fifteen minutes if drying tube is used, delaying placing pump in operation until after this meter warm-up and attachment of sampling tube. The gas flow meter should show 1 cu. ft. per hour rate, adjusting to this rate if necessary. The instrument is now ready for use and gas-air samples are drawn, via the position tagged tubes, from the area under fumigation, and should show on the meter as ounces per 1000 cubic feet. Sampling tubes should be loosely plugged with lambs' wool or muslin if insertion is to be made into flour or finely ground material. The sample-drawing time, however, should be sufficiently long to insure a true reading, varying with the size and length of the tubing from 30 seconds to several minutes. With 150-200 ft. of 1/4 in. OD tubing and a temperature of 70°F., this will approximate 7 min., 5 min. for 100 ft., and about 3 min. for a 50 ft. line. In all cases, too, the use of a

drying tube will require additional time in drawing reliable samples. This can be speeded by using a small vacuum pump to purge each sample line before it is connected to the TCA. This will bring the air gas mixture to the end of the sample tube so that the pump in the TCA moves the fumigant air mixture only through the gas analyzer.

In using the TCA, it should be borne in mind that the instrument is sensitive to a number of gases other than MB, AND THESE MUST BE ELIMINATED FOR A TRUE READING.

Carbon dioxide may occasionally be troublesome in this regard, particularly with fruits. If a pre-fumigation test indicated significant quantities, a tube of sorbing material (usually sodium hydrate, such as Caroxite, a Fisher Scientific Company product), should be placed in the sampling line.

After final readings of a fumigation, the fumiscope should be thoroughly purged by removing the last sampling tube and allowing the pump to draw pure air through the instrument for several minutes.

How to Use a Drager Detector

The Drager detector consists of a pump to draw the air gas sample through a calibrated detector tube. The ends of the glass detector tube are fused to seal the tube from contamination. These ends must be removed before drawing a sample through the tube. The detector tube should be inserted in the pump in such a way that the arrow on the tube points toward the pump. Several strokes of the pump are needed to draw an adequate sample of the fumigation atmosphere through the detector tube.

The concentration of phosphine, methyl bromide, or sulfuryl chloride can then be read directly from the printed scale. The limit of the stain indicates PPM of fumigant in theair. If there is no color reaction after drawing a sample through the tube it can be used for another sample. The detector tubes should be stored below 85°F. and protected from light. Under these conditions they have a storage life of two years. At lower storage temperatures they can be stored for longer periods without losing effectiveness.

How to Use a Gas Mask

Principle of operations: The gas mask, when properly assembled and fitted, is a compact air purifying unit which furnishes protection against those harmful gases or vapors listed on the canister label. During inhalation, the air enters the canister through the bottom and passes into the interior. Here the air is chemically purified or the harmful gases or vapors neutralized. The purified air then passes through the corrugated rubber tubing into the molded channel of the facepiece, some of these channels directing the purified air to the lenses to reduce fogging. During exhalation, the air is expelled from the facepiece through the exhalation valve which is so designed as to permit near normal conversation. This valve outlet also serves as a drain for moisture which may condense from the operator's breathing within the facepiece. An inhalation valve at the bottom of the canister prevents the exhaled air from being expelledthrough the canister.

Usage: The gas mask must not be used in an atmosphere deficient in oxygen. The canister label indicates the limitation as to percent of dangerous gas or vapor in which it is effective. The wearer should advance cautiously into the contaminated area and return to fresh air immediately if irritating gases are noted or if symptoms of distress are experienced.

In preparing the gas mask for use, the following steps are taken (a Wilson-WIG mask is used as an example; details will vary with other masks):

1. Remove from carrying case and examine visually for defects. Check all rubber parts and fittings for deterioration indicated by minute cracks in the rubber.
2. Check canister for effective date and gases for which effective. Canister must not be over four years old and seals must still be intact.
3. Place neck strap of canister harness around neck with laces forward, adjusting to carry canister weight in comfortable position.
4. Attach body strap to hold canister firmly against body.
5. Remove canister seal.
6. Loosen mask head straps to end tabs.

7. Fit mask to face and head, firmly against chin stretch strap; the head harness should come completely to back of head; adjust all straps for snugness, pulling top forehead strap last for securing tight seal.

8. Test mask, holding hand over air inlet on bottom of canister; mask collapses on inhalation if airtight.

9. If mask does not pass leakage test, tighten all clamps, connections, and straps, testing facepiece by grasping breathing tube and squeezing it closed.

Maintenance: After each fumigation usage the gas mask should be carefully checked for any necessary repairs. After disconnecting the breathing tube from the canister, the facepiece should be cleaned with soap and warm water, thoroughly rinsed, and swabbed with a mild disinfectant, drying at room temperature. The mask should then be reassembled, equipped with a new cannister with seal intact, and placed in carrying case, ready for emergency use.

Canisters are available in several sizes. They will protect the user only as long as the toxic vapor is removed from the air he breathes. The time is determined by the gas concentration, the rate of respiration, and the fumigant used. Contact the manufacturer for information on the length of time a canister can be used before being discarded.

SELF-HELP QUESTIONS

Now that you have studied this section, answer these questions. Write the answers with a pencil without referring back to the text. When you are satisfied with your answers, see if you are correct by checking them in the text. Erase your answer and write in the correct answer if your first answer is wrong.

1. What emergency telephone numbers should be known in advance of any fumigation?

2. Should warning signs be posted where fumigants are being used?

3. Should fumigants be applied from outside the structure whenever possible?

4. What is the minimum number of persons who should work on a fumigation operation?

5. What are some indications of poisoning from fumigants?

6. Are canister-type gas masks effective at high concentrations of fumigants?

7. Where can you find information on the proper canister to use with a fumigant?

8. When is a self-contained breathing apparatus required instead of a canister gas mask?

9. When should a suitable gas detector be used?

10. What are some fumigants that can be measured with a halide gas detector?

11. Where is it dangerous to use a halide gas detector?

12. How should a vacuum pump be used in conjunction with a TCA analyses?

13. What is the closest distance from a fumigation site that a TCA analyzer should be used?

14. What is the minimum number of sampling tubes that should be used with a TCA analyzer?

15. How is carbon dioxide eliminated from interfering with readings from a TCA analyzer?

16. What are some fumigants that can be detected with a Drager detector?

17. What should an operator do if irritating gases or symptoms of distress are noted in a fumigated area?

18. How should the facepiece of a gas mask be cleaned?

TYPES OF FUMIGATION ENCLOSURES

There are three common types of fumigation enclosures. Each has advantages for certain uses and none of them can meet all the needs for an enclosure to confine the fumes of certain chemicals until they have killed the pest.

Permanent Atmospheric Pressure Chambers

All fumigation chambers must be tight. Those constructed for fumigation Those constructed for fumigation purposes should have double walls, although in some instances single thickness materials are used to construct chambers for temporary or limited use. It is advisable to use double walls whenever possible and to use insulation materials between the walls. On double wall chambers the inner walls should be checked for tightness after they are sealed and before an outer wall is added.

Leaks are easier to locate and repair with only a single wall in place. It is advisable to use double walls and insulation material between the walls, especially if the chamber is built in an open area where existing weather conditions may affect chamber temperature. Chambers constructed in this manner will prevent a sudden rise or fall of temperature during periods of exposure. Drastic temperature fluctuation may interfere with insect kill or adversely affect products being treated. Existing rooms or buildings may be converted to serve as fumigation chambers; however, the same precautions must be taken to insure tightness.

In assuring the tightness of the fumigation chamber, it should be borne in mind that the outer wall is of little importance. It does act as a windbreak and prevents passing air from syphoning gas through possible openings. The inner wall is the one that has to be made tight. This can best be done by planning the structure carefully. In the case of a wooden frame building, sheet material should be used for the inner lining. The height and width of the building should be planned to conform to the dimensions of the lining material to be used. Pressed masonite, sheet metal (with exception of aluminum), and plywood are satisfactory lining materials. They are manufactured in different lengths and widths but the standard size is 4 feet in width and either 6, 8, 10 or 12 feet in length. The upright studs in frame buildings

should be exactly the height of the desired ceiling and should be soaked so that the sheets of lining material may be joined on centers of properly spaced studs.

The tightness of atmospheric pressure chambers has been stressed and is important; however, it is difficult to make them entirely tight. Regardless of how well constructed, some air leakage usually occurs. The lack of absolute tightness was taken into consideration in the development of approved fumigation schedules and, so long as the degree of tightness meets standard requirements, fumigation chambers will perform satisfactorily.

All permanent fumigation chambers, except those used to fumigate vehicles, should have false floors. They are required because gas-charged air must be made to move in a manner so that it is forced around and through the load. The distance from the subfloor to the false floor must vary according to the size of the chamber. This is necessary so that the amount of free air beneath the load will be sufficient to supply the air intake needs of the various blowers required for different size chambers.

False floors should be slatted with boards of appropriate thickness. These boards should not be more than 8 inches wide and should be spaced two or more inches apart.

If fumigation chambers are innerlined with plywood or masonite, the most likely places for air to escape are: where the sheets join each other along the sides of the chambers; where the upright sheets join the sheets that form the overhead ceiling; or where the bottoms of the sheets join the floor. Because fumigation enclosures are subjected to extreme changes in humidity and temperature, lining materials will expand and contract and eventually cause air leakage unless the materials are properly jointed. The lining sheets should not be joined closely together; a space of about 1/8 inch should be left between them to allow for expansion. These 1/8-inch openings should be filled by forcing caulking material into and along the sides of the seams. Common roofing tar is satisfactory for this purpose. It does not harden like putty but will expand and contract with the ceiling and will not separate or leave openings. Two-inch lath strips should be nailed tightly over the caulked seams. Rust-resistant sheet iron is ideal for lining fumigation chambers.

It does not require painting when ethylene dibromide is used. If the sheets are overlapped about 1 inch, fewer nails will be required. When one edge of the sheet has been attached to the studs, a liberal amount of caulking material should be placed along the edge before the overlapping sheet is attached. The overlapped area should be covered with lath strips and nailed at frequent intervals. The nails should be confined to the area where caulking material exists.

Fumigation chambers may be constructed with cement slab floors and walls of brick or cement blocks. Pressed masonite, plywood, or sheet metal—except aluminum—should be used for the ceiling with wood joists. Walls and ceilings made of wood, cement blocks, or bricks require inside finishing to prevent gas leakage.

Fumigation chambers constructed of cement, cement blocks, or bricks may be made sufficiently tight by an application of cement and water if only methyl bromide or cyanide is to be used as a fumigant; if wood is used, it must be painted with an approved paint. If ethylene dibromide is to be used, false floors and all inner linings, with the exception of sheet metal, must be given two coats of gas-resistant paint or varnish. Floors, ceilings, and walls—other than sheet metal—not sealed with vinyl plastic must be painted with at least two coats of the approved paints or varnishes prior to use.

The doors are responsible for most of the leakage in fumigation chambers. This can be prevented to a great extent by using straight material, larger than usually used in the construction of door frames. The door should not be larger than needed to accomodate loading of products, should be of double thickness to minimize warping, and should be equipped with strong, sturdy hinges. Two parallel strips of moulded rubber gaskets should be cemented on the door facing so that when the door is shut they are compressed to form a tight seal. A wedge or leverage-type latch, similar to those used on ice houses, should be used to hold the door closed. Despite these precautions, the gaskets may lose resilience or the hinges will become worn or sprung and the door may warp.

In order to overcome present or possible future difficulty with fumigation chamber doors, it is advisable to provide for cross braces while the chamber is being constructed. Cross braces placed at positions about one-third and two-thirds of the height of the door usually suffice to insure tightness. Four

iron bolts should extend through the door frame, threaded ends out at a sufficient distance from the door to allow it to open freely. Cross braces should be made of heavy timber or pieces of angle iron; holes may be bored in the ends to accommodate the bolts, and wing nuts may be used to tighten the braces against the door.

Tarpaulin Chamber

A method often used to confine fumigants is the tarpaulin. This may be polyethylene film, plastic-coated nylon, or any other tarpaulin material that is impervious to the fumigant. These tarpaulins can be moved to the fumigation site where commodities, equipment, or vehicles can be covered and fumigated. This type of fumigation enclosure conforms well to the load. It does not require large amounts of gas to fumigate excess space because the air space between the load and the tarpaulin is minimum. However, adequate head space must be provided above the load.

Operators should realize that fumigation tarps are not in the same class as tar-coated canvas or other water-resistant tarpaulins. Fumigation tarps are quite expensive. They should never be used for any purpose other than fumigation. They should be handled carefully and never dragged along the ground. After use, they should be cleaned, dried if necessary, and folded and tied. If they are not well cared for, they will be torn or the plastic coating will come off in areas that have been exposed to chafing. Injury of this type is difficult to detect unless the tarpaulins are draped over poles, tent fashion, and inspected from inside. Air leakage up to a certain point is permissible, but beyond that point tarpaulins will not hold enough gas to kill insects.

When tarpaulins are used for fumigating commodities, the most serious loss of gas may be caused by absorption in earthen floors or escape around the bottom edges of the tarpaulin. Fumigation should be conducted on asphalt or cement covered surfaces or right wooden floors, if possible. Thin, expensive plastic sheeting, laminated sisal-kraft paper, or lightweight roofing paper must be used to cover leaky wooden floors or loose or sandy ground to prevent gas penetration. The sheeting should cover the entire area intended to serve as a floor for the chamber. The sheets should be overlapped about six inches. Sand or earth may be used to cover them to a depth of one or more inches as protection against punctures. Methyl bromide losses can be reduced by thoroughly wetting

uncovered earth prior to releasing the gas. Much gas will enter sandy soil, despite packing and wetting.

In order to prevent gas leakage around the bottom of the tarpaulin, it is necessary to arrange the load so that at least two or three feet of the tarpaulin is available to extend outward from the load and lie flat on the surface. The surface should be smooth and even. An effective seal can be made by pouring loose sand on the flat portion of the tarpaulin or by using overlapping sand or water snakes, which are long cloth or plastic bags about 5 or 6 feet long and 3 or 4 inches in diameter, filled with sand or water.

Tarpaulins, regardless of how good they are or how carefully they are used, are only substitutes and should be used only when chambers are not available. They have many objectional features. Even the best of them have many very small openings that allow some gas to escape. They are thin and, since there is no second wall to retain static air, the movement of outside air will cause them to lose gas through any openings that may exist. When tarps are used and exposed to sunlight, overheating may be encountered. Excessive heat may cause serious injury to plants or perishable commodities.

It is necessary to form a good seal between the bottom edges of the tarps and the floor and it is also necessary to place empty crates, empty metal drums, or other inert objects on top of each load to allow for adequate space to mix air and gas. In effect, a fumigation chamber is built each time a tarp is used and this is both time consuming and expensive. In addition, more fumigant may be required as some schedules require higher dosages for tarpaulin fumigations in order to compensate for loss of gas. For the above reasons, permanent chambers should be erected and tarpaulins should not be used in situations where repeated or continuing fumigation is anticipated.

If regulatory fumigations are done under tarps, they must be checked with T/C analyzers to be sure that the correct dosage has been applied and uniformly distributed at the start, and to detect unusual leakage which often occurs with these fumigations.

Vacuum Chambers

Vacuum fumigation chambers are less frequently used. They are commercially built and must be able to sustain vacuum equivalent to 24.5 inches mercury. Because of the strength and accessory equipment needed to sustain the required vacuum, these chambers are expensive to build and equip and are generally limited in size.

Before introducing the fumigant, the vacuum must be increased to the required level. The mechanics of operating a vacuum fumigation chamber should be supplied by the manufacturer building the chamber.

Advantages of vacuum fumigation over atmospheric pressure fumigation are that the exposure period is shortened, the fumigant will penetrate tightly baled commodities more easily, and a check of the chamber is built into each treatment. If the chamber is not tight it is impossible to draw and maintain a vacuum. Finally, the amount of fumigant required is less because there is no leakage.

Use of Railway Cars and Other Wheeled Carriers as Fumigation Chambers

Many boxcars, vans, and other wheeled carriers are unsuitable for use as fumigation chambers due to the inability to contain the fumigant within them. Some, however, may be used. When they are used there is normally some temporary sealing required in order to prevent gas leakage around doors and vents. Four inch masking tape is ideal for this purpose provided the surface on which it is to be applied is clean and dry.

Fumigation in wheeled carriers is convenient in that the commodity may be treated without being loaded and unloaded. Also, the fumigation kills the insects in the free space of the carrier and live pests do not remain behind to infest the next load.

Railway companies are usually willing to permit fumigation in their equipment. Whenever a railway car or wheeled van is used as a fumigation chamber it should be checked for tightness prior to loading, if possible. Any obvious leaks should be sealed. Any wheeled carrier that cannot be adequately sealed should be covered with a gas tight tarpaulin or plastic sheet.

Railway cars should be fumigated on isolated sidings. Highway vehicles should also be placed in protected sites. Neither should be allowed to move until the fumigation period is completed. If they are moved, the vibration caused by the moving ruptures the seal and the fumigant escapes. Appropriate warning signs should be placed on main doors and hatches with instructions for adequate ventilation before it is entered for inspection or unloading.

The two commonly used fumigants for wheeled carriers are methyl bromide and phosphine. In general the techniques for sealing and fumigant application are the same as those described for chamber fumigation.

Greenhouse Fumigation

For many years fumigants were used for the routine control of insect pests in greenhouses. Calcium cyanide dust generating HCN gas with the aid of moisture from the air, and nicotine volatilized as a gas by ignition or other means, were both commonly used. Recently the aerosol method if dispersing insecticides and evaporation from steam pipes have found favor. This permits treatment of large areas of greenhouse space quickly and economically.

In computing the dosage of insecticide to be applied, the cubic capacity of the greenhouse must be known. Any space occupied by plants, benches, soil, etc., should be ignored. At present, a wide range of insecticides and acaricides is available. These include liquefied gas aerosols, smokes, fogs, and gases.

When aerosols, fogs, smokes, steam pipe fumigants and gases are applied it is necessary to close all vents. Temperature should be maintained above 20°C. (68°F.) but kept below 35°C. (95°F.). Outside wind velocity is important. It is not practical to carry out treatments when the wind velocity is above 10 miles per hour because when the wind outside is too strong, there is uneven distribution of the insecticide in the greenhouse, resulting in underdosing in some places and overdosing in others to the point of plant injury.

In applying liquefied gas aerosols the term aerosol is used to describe the form in which the insecticide is dispersed after it leaves a special cylinder. On discharge into the open the liquid vaporizes and leaves particles of insecticide suspended as a fine mist in the air. This form of application is distinguished from the generation of fogs and smokes. Aerosols are economical, however, they do not penetrate soil and they are not effective against slugs or snails.

Insecticidal and acaricidal smokes are useful in smaller greenhouses. The toxicants are mixed with a combustible material in a special container that permits ignition and discharge. Generally speaking, the smoke cause less plant injury than the aerosols.

The production of fogs is a modification of a spraying technique. By means of compressed air, spray concentrate solutions are forced through atomizers so that small droplets are formed.

True vapors or gases are still used in certain ways for greenhouse pest control. A method of some value is to paint a slurry of some toxicant on the steam pipes. The gas is usually volatilized during the night.

Methyl bromide is not usually a suitable fumigant for general release in a greenhouse because it diffuses so rapidly through small holes that it is difficult to maintain the concentration needed to kill the pests.

Many of the materials used in aerosols are extremely toxic to humans. It is necessary that persons applying aerosols wear a respirator and protective gloves and clothing. The respirator should be of the industrial type (employing a filter type canister). The canister recommended is for "organic vapors, acid gases, smoke and dust." The protective clothing consists of a work suit completely covering the arms and body and long rubber gloves. Warning signs should be posted on all greenhouses being fumigated to prevent accidental entry.

Fumigation of Grain in Bulk

One of the most important considerations in the fumigation of bulk grain is the diversity of structures used for storage. The shape, size, and type of construction create special problems in achieving and maintaining the gas concentrations required. Grain storage units are usually broadly classified for fumigation purposes as follows:

1. Upright (vertical) storage. In this type the height is greater than the length or width.
2. Flat (horizontal) storage. One dimension, either length or width, is greater than the height.
3. Farm type bins and storage units.

Direct mixing of the fumigant is used in vertical storage situations. The fumigant is applied to the grain so that it is distributed as evenly as possible from the beginning of the treatment. This method is often used when infestation is general throughout the mass and there is access to the grain stream as the infested grain is being run into a storage for the first time or is being transferred from one bin to another. Only liquid or solid type fumigants are used in this way. This is a simple method because good results can be obtained if the application is done by hand.

The Surface Application Method is used in flat storage situations and utilizes liquid type fumigants. The liquids are sprayed evenly over the top surface of the grain. The vapors slowly evolve and diffuse downward through the grain. Under modern conditions this method is usually used only when the grain cannot be turned or in an emergency situation.

In Farm Storage Fumigation the gas-tightness of the structure is an important factor because the bulk grain is not large enough in itself to retain vapors once leakage begins. Steel, concrete, or tight wooden structures are usually satisfactory. Most wooden storages are leaky and it is advisable to line the floor and walls on the inside with stout roofing paper. Avoid fumigating in windy weather.

The best way to apply liquid fumigant to small storages is by spraying the surface from the outside of the building with the aid of a stirrup pump. Some liquid fumigants, such as chloropicrin, are supplied in one pound cans. In some applications it is convenient to puncture the cans, invert them, and thrust the opening about six inches below the surface. Aluminum phosphide tablets have also proved promising for the treatment of small storages.

Piles of grain, large or small, may be treated by surface application in any of the ways described above. However, only partial kills may be expected if the grain is not covered with a gas-tight tarpaulin either before or immediately after the application of the fumigant.

Treatment of localized areas in a grain mass is often a useful technique for dealing with incipient infestations. These "spots" are usually recognized and defined by a local rise in temperature. Liquid type fumigants applied through tubes or aluminum phosphide tablets are the best materials to use.

The application of fumigants to large masses of grain in various types of structures involves considerable amounts of fumigants. Under these conditions safety measures are of prime importance. Only fully trained operators should be entrusted with these fumigations. The operators must be fully protected at the time of application. This is especially important when using liquid fumigants. Proper ventilation of the working space where the materials are being applied is necessary. Other persons working in the vicinity must be warned that a fumigation is in progress.

Soil Fumigation

Soil fumigants are pesticides which exert their toxic action as gases, and are applied to soil for control of nematodes, fungi, weeds, insects or bacteria. Some are broad-spectrum materials that can be used for control of many kinds of pests, while others are suitable only for control of a limited number of types of pests. Soil fumigants are usually formulated as gases or liquids, and the vast majority are halogenated hydrocarbons. Gaseous formulations are distributed in pressurized cylinders, and liquid formulations in metal or plastic containers. Granule or gel formulations are available for a limited number of compounds. For optimal pest control, soil fumigants must be applied under specific environmental conditions, and most are highly toxic to living plants. These properties must be evaluated in detail in relation to each specific soil fumigation need.

Environmental conditions: Soil for fumigation should be in a "seed-bed" condition. It must be of uniform tilth, contain as little nondecomposed organic matter as possible, and be of adequate soil moisture potential, but not wet. Soil temperature should be between 50° and 80°F. If the soil is too cold, too moist, not prepared properly, or contains too much nondecomposed organic matter, the soil fumigants will not diffuse properly and good pest control will not be obtained. If the soil is too dry or the temperature too high, the fumigant will be released too rapidly, resulting in poor pest control. In Michigan, it is best to apply soil fumigants during the early part of fall. Long-range planning is necessary for proper use of soil fumigants. Because of the sorption properties of organic (muck) soils in relation to the chmical properties of soil fumigants, it is usually necessary to use twice the normal mineral soil rate of the chemical for good pest control in these soils.

Fumigant and formulations: Methyl bromide, chloropicrin, and mixtures of these two chemicals are the most commonly used soil fumigants formulated as gases. These materials must be applied under a tarpaulin or plastic cover. They can be used on a broadcast, row, or specific-site basis. These materials are phytotoxic, must be applied on a preplant basis, and the soil must be aerated prior to planting. Some plants are highly sensitive to brominated compounds and such materials cannot even be used on a preplant basis in cropping systems including these plants.

1,3-D (1,3-dichloropene and similar mixtures) EDB (ethylene dibromide), DBCP (1,2-dibromo-3-chloropropane), and mixtures of 1,3-D and chloropicrin or methyl isothiocyanate, or EDB and chloropicrin are the most commonly used soil fumigants formulated as liquids. They must be injected to an appropriate soil depth (usually 6-8 inches, but this can vary with the objective of the treatment). The soil should be slightly sealed after application. The materials can be applied on a broadcast, row, or specific-site basis. All of the compounds except DBCP are phytotoxic and must be applied on a preplant basis. The soil must be aerated prior to planting. With some crops, DBCP can be applied on an at-plant or postplant basis. Emulsifible concentrate formulations of DBCP are available and in specific cases the material can be applied through irrigation water. Some plants are highly sensitive to brominated compounds and these materials cannot be used, even on a preplant basis, when these plants are used in a cropping system.

In some locations, DBCP can be obtained in a granular formulation. For good pest control, it must be incorporated or irrigated into the soil. Gel formulations of methyl bromide and combinations with chloropicrin are available. These must be injected into the soil and can be used without a tarpaulin or plastic cover. Soil fumigants are toxic chemicals and must be used with the safety precautions outlined in the commodity, structural, and greenhouse fumigation sections.

Soil fumigation equipment: Equipment is commercially available for broadcast, row, and specific-site application of gaseous, liquid and solid formulations of soil fumigants. Application equipment can be rented from fumigant distributors, and custom operators service in some geographical areas. Many agricultural producers have successfully constructed their own soil fumigation equipment. Soil fumigants are corrosive chemicals, and fumigation equipment should be constructed out of appropriate materials. Equipment must be cleaned with appropriate solvents immediately after each use.

SELF-HELP QUESTIONS

Now that you have studied this section, answer these questions. Write the answers with a pencil without referring back to the test. When you are satisfied with your answers, see if you are correct by checking them in the text. Erase your answer and write in the correct answer if your first answer is wrong.

1. What are some satisfactory lining materials for a permanent atmospheric pressure fumigation chamber?

2. Where are air leaks most likely to occur in an atmospheric pressure fumigation chamber?

3. What should be used to seal wood liners of an atmospheric fumigation chamber?

4. What types of material can be used to make a tarpaulin fumigation chamber?

5. Where do the most serious losses occur with a tarpaulin fumigation chamber?

6. Why are fumigation dosages higher in tarpaulin than in permanent fumigation chambers?

7. What are the advantages of using a vacuum fumigation chamber?

8. Where should railway cars be placed for fumigation?

9. What is the maximum outside wind velocity for fumigation of a greenhouse?

10. Do aerosols penetrate into soil when used in greenhouses?

11. Do smokes generally cause more plant injury than aerosols in greenhouses?

12. How are fogs produced in greenhouses?

13. What safety equipment is needed when fumigating a greenhouse?

14. What are the three broad types of bulk grain storage units?

15. How are fumigants applied to bulk grains in the surface application method?

16. How are "spots" in bulk grains recognized?

17. What soil conditions are required for effective soil fumigation?

18. How are liquid soil fumigants applied?

19. What types of formulations of soil fumigants are available?

FUMIGATION PROCEDURES

General Information

This section deals with general fumigation procedures which are essential to the safe, effective use of fumigants.

The use of fumigants is often regulated by local governments. Regulations are designed to protect the health of those applying the fumigants and the public in general. Regardless of whether the treatments are made it permanent installations or are carried out once only in a particular place, it is necessary that all regulations be observed.

When conducting a fumigation, always:

1. Inspect the premises and make sure the fumigation can be conducted without endangering anyone in the area. Post the area with warning signs.
2. Select the fumigant which is registered by the E.P.A. for the work involved.
3. If the fumigant of choice has no natural warning agent properties, consider the use of a combination of fumigants to obtain such a warning agent. However, do not violate the residue tolerances.
4. Seal the structure or commodity effectively. This is the most important part of any fumigation and is the key to a successful fumigation. Brick or cement buildings in good repair can usually be fumigated by sealing all external openings. Doors and windows should be firmly closed and taped or caulked. REMEMBER, fumigation may be successfully carried out in any structure that can be made gas-tight for the length of time required.
5. Place the injection equipment in such a manner as to assure initial distribution of the gas.
6. If circulating fans are to be used, place them in a manner which will properly circulate the gas.
7. Calculate the dosage. All dosage recommendations are made on the basis of volume (cubic content) of the structure or bushels or tons of grains and other commodities. For regularly shaped square or rectangular

structures, dosages are calculated by multiplying length by width by height. If the structure is irregular, the volume of each unit should be calculated separately and then added together. If the structure has a peaked roof, the average between the height of the side wall and the distance from the lowest floor to the top of the roof may be taken as the height dimension in calculating the volume.

8. Introduce the fumigant using fans and heating apparatus if warranted. If practical, only a fraction of the fumigant should be applied. Test for leakage using approved detectors and correct leaks if discovered. Then introduce the remaining fumigant.

9. Protect the fumigation during the exposure period. No unauthorized personnel should be allowed in the fumigation site. Periodically check the structure for leaks.

10. After the exposure period is completed the structure should be aerated; open as many doors and windows as possible. Ventilators and circulating fans should be used to aid in withdrawing the fumigant. As soon as the steps for initial venting are taken, the fumigators should withdraw from the immediate vicinity of the fumigated structure and wait 30 minutes before re-entering. Check for presence of fumigant and continue aeration procedures until the structure is free of gas.

Loading of Chambers

The way commodities are loaded in a chamber has an effect on fumigation efficiency that should be known by all operators. If fumigation enclosures are loaded with commodities that occupy about 3/4 the capacity of the room, fumigants have less tendency to stratify or escape from the chamber than they do if excessive free air space surrounds the load. For example, if a fumigant has been properly applied in a normal chamber-load of fruit, the gas will come in contact with all of the fruit almost immediately and will penetrate at a rapid rate. Air space between the fruit and the containers would tend to hold gas-charged air until lethal dosages of gas had been taken up by the fruit. Absorbed gas would remain in the fruit even though the chamber had air leaks.

If, by comparison, a piece of harvesting machinery were treated in a similar chamber, practically no fumigant could be absorbed by the metal. All wall space in the chamber would be exposed to the circulated air and the gas would escape rapidly through any opening which might exist in the chamber. Fumigation of mechanical equipment can be made more effective by placing a small blower on the floor and directing the outlet air toward the highest portion of the machine.

A free air space should be left over all commodities. The amount of space will be determined by the size of the chamber. The table below should be followed:

Size of Chamber	Amount of Headspace
up to 2,000 cu. ft.	12 in.
2,000 to 8,000 cu. ft.	20 in.
8,000 and above	24 in.

In discussing the loading of chamber, the terms "overloading" and "underloading" are used to express bulk of commodities and not weight. Air circulation around and through commodities being fumigated is very essential. Space must exist above the top of the load in order that air and gas may be properly mixed and circulated as the fumigant is being introduced. If air space in that area is limited, gas concentrations will become excessively high during the introductory period. Much of it may be absorbed by commodities in the upper portions of the load before adequate air movement can distribute it throughout the chamber. Space must be provided beneath the load in order that air circulation blowers may recover air as rapidly as it is discharged. Overloading of chambers restricts and retards gas distribution and results in uneven concentrations of gas, incomplete kill of insects, and increased injury to susceptible commodities.

Stratification of gas will not occur during fumigation if (1) it is properly introduced over the load, (2) proper type fans are used, and (3) provisions are made for the air and gas to circulate throughout the load.

The nature of commodities should be taken into consideration in arranging loads for fumigation. Dry, porous commodities such as hay, staw, corncobs, or similar products should be loaded in such a manner that a few inches of space are provided between the load and the side walls of the chamber. Also,

they should be loaded whenever possible to provide space between tiers of bags, bales, etc. Products that do not absorb gas rapidly and that allow sufficient space between individual items to permit air to move downward freely may be placed directly against the walls of the chamber.

A certain amount of the fumigant is absorbed by practically all treated commodities. If chambers are overloaded with dry, sorptive commodities, the concentration of gas when first applied will become very high in the limited air space. Highly sorptive commodities will consume gas rapidly.

Fumigation chambers that are only partially loaded present problems which, in some respects may be more hazardous than those in overloaded ones. In the first place, the air circulatory systems designed to move air in loaded chambers cannot function properly in empty or partially loaded ones. In loaded chambers, the air is forced outward above the top of the load and must be recovered by blowers after it has passed around and through the load. If the bulk of the load is insufficient to cause the air to travel in that manner, it will follow the course of least resistance. Properly installed air circulation units should direct discharged air along the ceiling and against the opposite end of the enclosure. Intake air should be recovered from beneath false floors. If the load is insufficient to partially restrict air movement between discharged air and recovery air, the course of circulation will become triangular in shape. That is, it will follow a straight line from the blower to the opposite end of the chamber and return directly to the bottom of the chamber beneath the blower. In such instances, partial loads will receive an unnecessary amount of gas in the limited areas through which the air passes and not enough gas elsewhere in the chamber.

The distribution of gas in underloaded chambers can be controlled by arranging loads according to the nature of the commodities involved. Properly placed loads can be made to provide effective insect kill and even out the amount of gas absorbed by the individual items that compose the load. If the commodities are closely packaged or packed in square containers, they may

be arranged to cover the entire surface of the false floor in such a manner that the movement of air through them is restricted. Sufficient air restriction will cause the blower to draw intake air through all portions of the load. If the load is composed of commodities or containers that offer little resistance to air movement, it should be concentrated in the portion of the enclosure nearest to the air circulation unit. The unoccupied portion of the false floor should be covered with paper, plastic sheeting, or other air-resistant material. In such an arrangement, all blower intake air must pass through the load and all of the commodities will be exposed to the gas.

Regulatory fumigation schedules were designed for use in fully loaded chambers. Residue tolerances set by the Environmental Protection Agency are governed to some extent by the amount of residue that accumulates in food or feed products when fumigated with minimum dosages required to kill various regulated insects. When normal dosages of fumigants are used to treat partial loads, residues in the commodities will increase and perishable commodities will become more subject to injury. For these reasons, appropriate size chambers should be used whenever possible or empty crates or other objects should be added to simulate normal loads.

Facts About Air Movement

Most fumigants in use prior to the development of methyl bromide and other modern fumigants were applied without air circulation. It was not necessary when sulphur dioxide smoke was used as the heat generated by burning sulphur caused sufficient air movement to distribute the gas among the products under treatment.

The modern fumigants used to treat commodities definitely require air circulation. In order to prevent possible injury to commodities and to comply with tolerances fixed by EPA, only the minimum dosage necessary should be used. The weight of the gases and their penetrating abilities make it imperative that they be mixed with the air and circulated in such a manner that the gas will come in contact quickly with all of the commodities in the load. Without adequate air circulation, exposed commodities would trap and hold excessive quantities of the gas and there simply would not be enough to go around.

Various types of air movement equipment may be used to circulate air and gas in fumigation chambers. Satisfactory air circulation does not depend entirely on what is used to circulate the air but more on how it is used. For example, 12 or 14-inch blade office-type electric fans may be used satisfactorily under some circumstances. Such fans are adequate to prevent gas stratification when fumigating such items as farm machinery. They may be used, also, in small chambers loaded with loosely packed commodities, provided the wall of the chamber opposite the fan is close enough for air to strike it with sufficient force to cause a rebound. Small blade-type fans are not satisfactory if chambers are loaded with tightly packed commodities or if the chamber is so large that the air loses its velocity before it reaches the opposite wall. It should be borne in mind that fans were designed to stir up air; blowers were designed to move it from one place to another. Unless small blade-type fans are housed and provided with air-intake ducts, they recover only the air that surrounds them. Such movement of fumigants will result in overdosages in the area affected by the fan and underdosages elsewhere in the chamber.

When fumigating soil in bins or in the field, air movement must be retarded for effective fumigation. This can be done in several ways. After the fumigant is injected into the soil the surface can be packed to prevent aeration. A more effective seal can be made by soaking the soil surface with water. Another efficient method of sealing the soil surface is to cover it with polyethylene film. The soil type and condition and the fumigant used will determine the best method of sealing the surface.

Facts About Air Circulation Equipment

Squirrel cage blowers with electric motors or gasoline engines are superior to blade-type fans for circulating air in fumigation chambers. There are various types and sizes of blowers. In general, the principle upon which they operate is much the same. A series of parallel, concave vanes are used to propel air. They are enclosed in such a manner that the air they pick up can only be expelled through an opening provided for the purpose. Incoming air is channeled through a fixed opening. Air passing through the blower is partially compressed and expelled with considerable force. The air that

supplies the blower is drawn in rapidly. Blowers must be mounted so that the air is discharged above the top of the load. A duct should be attached to the blower in such a manner that intake air must originate from beneath the loads. It is possible to visualize the manner in which blowers move air in and around commodities by realizing that the discharged air overfills the air space above the load and is forced to go downward, wherever possible, through the load. The resultant push-and-pull effect causes air to move constantly through even closely packed commodities.

In selecting blowers for fumigation chambers, it is important to consider first the fumigant to be used. When using methyl bromide, blowers with a rated cubic foot per minute output sufficient to recirculate the number of cubic feet of air in the chamber about every four or five minutes may be used. If ethylene dibromide is to be used, more powerful blowers will be necessary because the air in the chamber must be recirculated at least every two minutes. Blowers should be mounted near the ceiling on the back walls of the chamber whenever possible, although they may be mounted outside with air intake and outlet ducts entering the chamber near the floor and the ceiling. If blowers are mounted outside, it is extremely necessary that the duct work be perfectly tight; if not, outside air will be drawn in before it reaches the blower, or air will be blown out between the blower and the chamber.

Sometimes an F.M.C. system, which has a blower mounted beneath the false floor near the center of the room, is used. Air is discharged through an upright air tube against the tip of an inverted cone or deflector which is mounted on the ceiling. The air spreads in all directions and is recovered from the pit provided between solid floor and the false floor. This unit is highly satisfactory inasmuch as it not only circulates the air properly but also eliminates possible chamber leakage.

If tall grain elevators require fumigation, a circulation system should be installed. Generally, a closed system is required unless the entire structure is fumigated at one time. These systems must be designed so they will be adequate for the size of storage and the commodity stored (example: for wheat, .025 cubic feet of air per minute per bushel should be circulated). Circulation systems for large elevators should be designed for each establishment.

Aerating Fumigation Chambers

Free gas should be released and commodities aerated immediately following fumigation. It is important to consider and protect human health at all times. When a fumigation chamber is inside a packing house or any other enclosure where workmen are likely to be present, intake and exhaust stacks should be provided. The exhaust stack must lead outside the building. The intake and exhaust stacks should be opened after the fumigation exposure is completed. The normal air circulation equipment in a chamber can be made to conduct air from the chamber to the outside. When a chamber is outside a building, it may be aerated safely by opening the door slightly at the beginning of the aeration period and turning the blower on. The door should be held in the partially open position so it cannot accidentally close. Air discharged from the blower should be vented to the outside of the chamber. If the door should accidentally close, the partial vacuum created by the blower may damage the chamber. No one should remain near the door or the exhaust when the blower is turned on. The doors may be fully opened after about 15 minutes, but workmen should not enter the chamber until it has been aerated for at least 30 minutes and checked with a halide detector.

When aerating loads under tarps, in buildings, or on still humid days, an opening should be made by lifting the tarp on the end opposite the blower and discharging the fumigant with the blower through an opening near the blower. If they are aerated in the open and a breeze is blowing, the end or side of the tarp opposite the direction of wind movement should be lifted first, then the portion of the tarp on the windward side may be opened safely. If the first opening is made on the windward side, concentrated gas will be forced backward and may endanger operators. Occupants, other than fumigation operators, should vacate buildings before tarps are aerated.

SELF-HELP QUESTIONS

Now that you have studied this section, answer these questions. Write the answers with a pencil without referring back to the text. When you are satisfied with your answers, see if you are correct by checking them in the text. Erase your answer and write in the correct answer if your first answer is wrong.

1. How is the volume of a structure with a peaked roof computed for a fumigation operation?

2. How much time should elapse between aerating a fumigated structure and entry of personnel into the structure?

3. Why should headspace be left above the commodity being fumigated in a chamber?

4. What are some of the difficulties in properly fumigating underloaded chambers?

5. Why should fumigation chambers be equipped with means of circulating air?

6. How can air movement be retarded in soil that is being fumigated?

7. Where should an air blower discharge its air within a fumigation chamber?

8. How does the FMC blower system work?

9. How should a fumigation chamber be aerated if it is located inside a building?

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